NuFact08 Perspectives

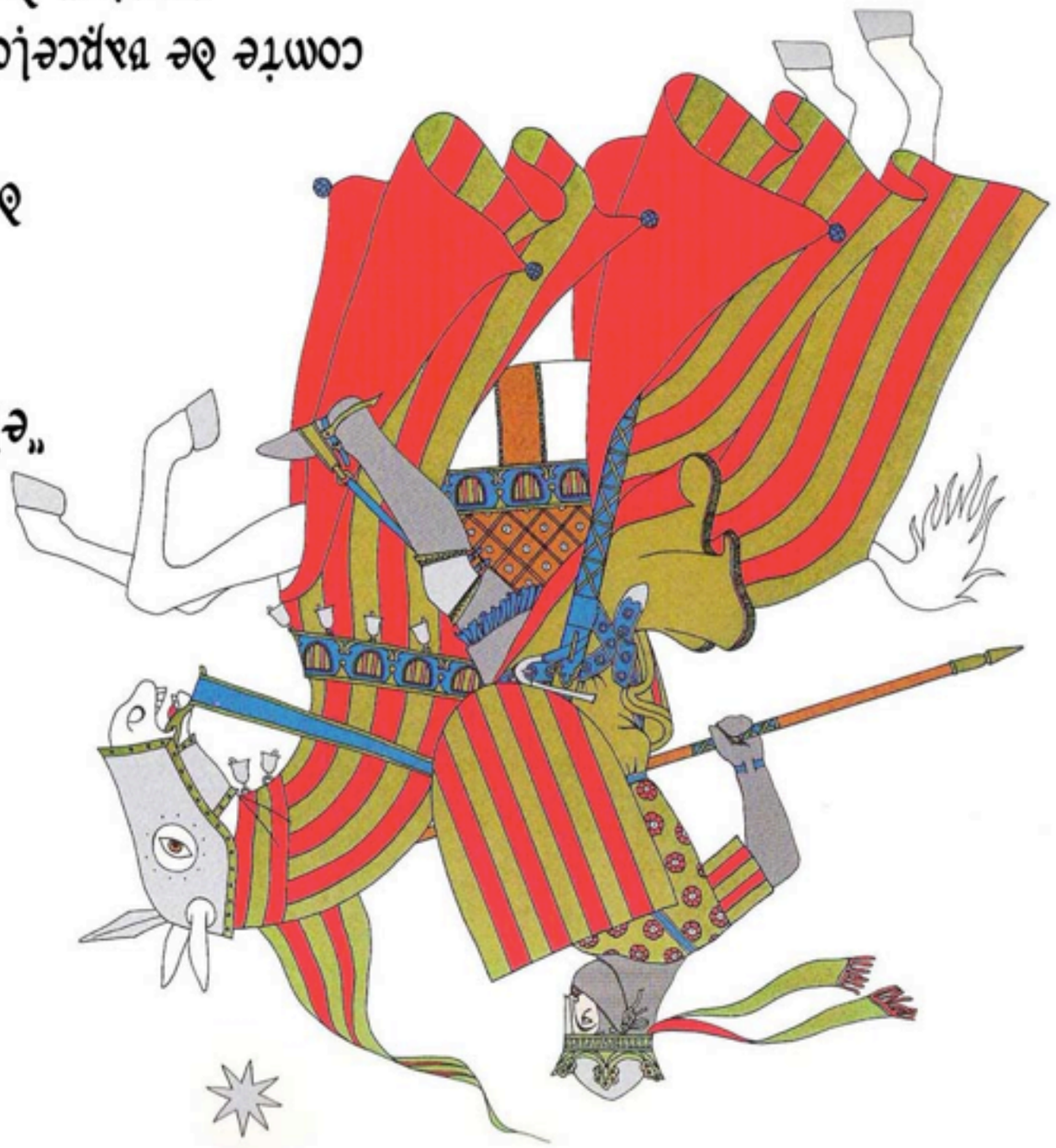
Chris Quigg

10th International Workshop on Neutrino Factories, Super beams, and Beta beams


AYUNTAMIENTO DE VALENCIA
VALENCIA DE CABLE

Jaume I
"el conqueridor"
(1208 - 1276)

Rei d'Aragó
de Mallorques
de València
comte de Barcelona i d'Urgell
senyor de Montpeller



2008 Premio Rey Jaime I: Investigación Básica

$9.5 M for NOvA


Fermilab is back!
CELERATING SCIENCE FOR AMERICA
Fermilab
DEPARTMENT OF ENERGY
UNITED STATES OF AMERICA

NuFact99: *Questions of Identity*

Do neutrinos oscillate?

What are the neutrino masses?

Is neutrino mass a sign of (nontrivial) BSM physics?

Does the evidence require more than 3 ν species?

Can we find evidence for a sterile ν?

Could ν masses be special (Majorana, scale ≫ EW)?

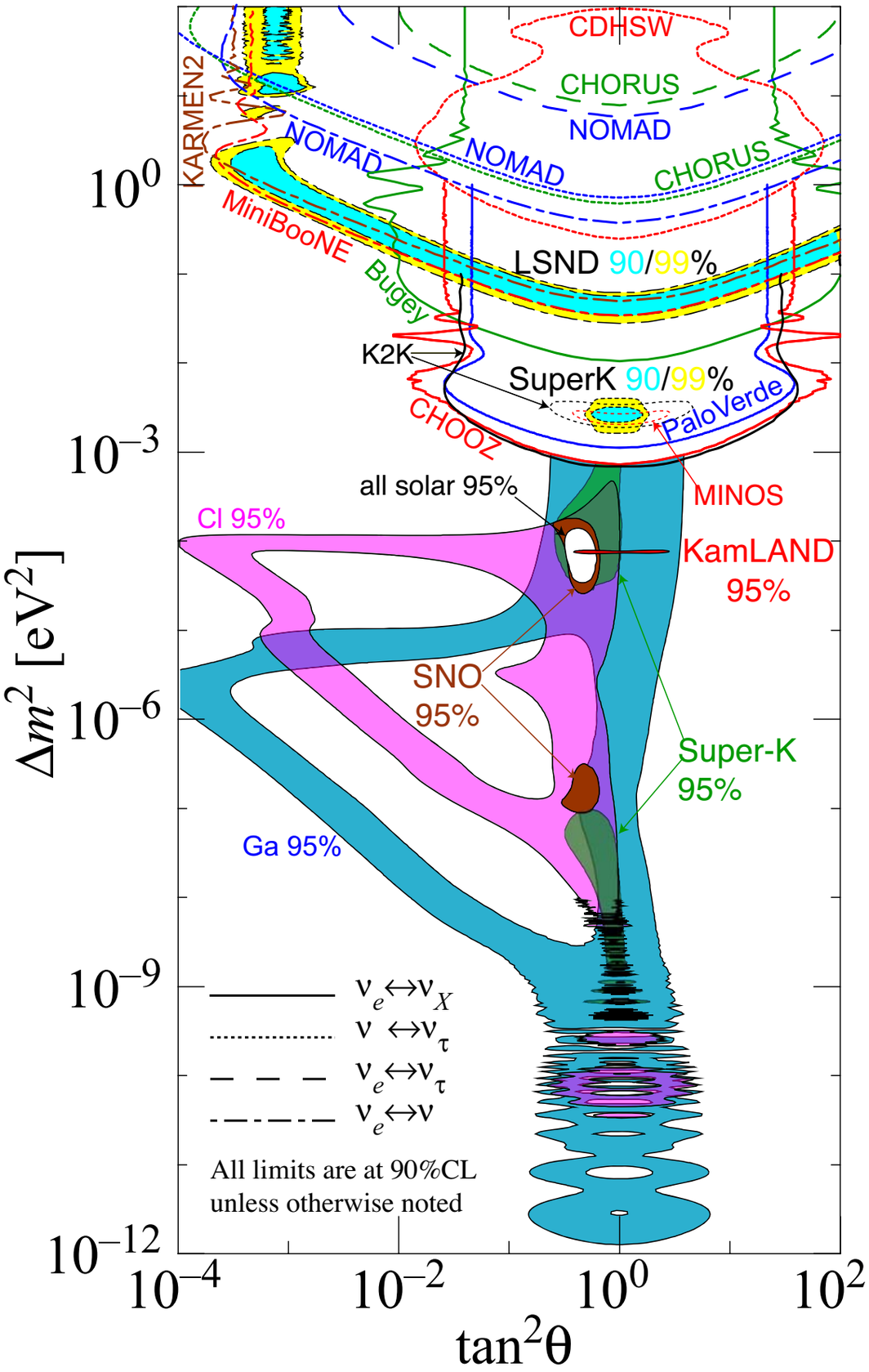
How could *light* sterile ν arise?

Are ν mixing angles large? maximal?

Do ν masses probe large extra dimensions?

Can we detect CP violation in ν mixing?

hep-ph/9908357



http://hitoshi.berkeley.edu/neutrino

Three-neutrino mixing formalism

3 ν masses, m_1, m_2, m_3

$$\mathsf{U} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

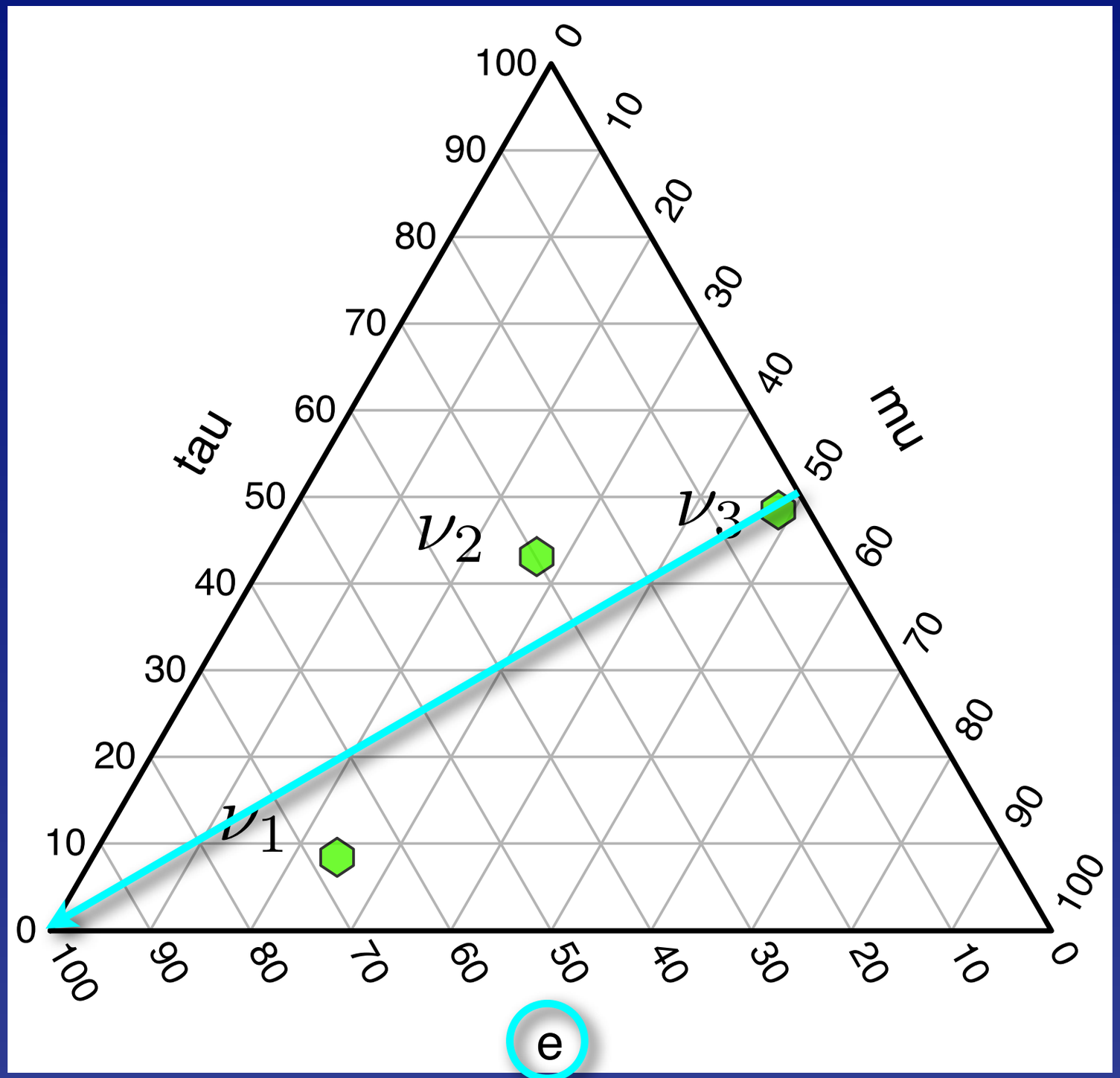
$$\cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{i\varphi_2} & 0 \\ 0 & 0 & e^{i\varphi_3} \end{pmatrix} \text{ if } \nu = \bar{\nu}$$

3 mixing angles
1 Dirac phase
2 Majorana phases

$$30^\circ \lesssim \theta_{12} \lesssim 38^\circ \text{ solar}$$
$$35^\circ \lesssim \theta_{23} \lesssim 55^\circ \text{ atm}$$
$$\theta_{13} \lesssim 10^\circ$$

CP phase δ unconstrained

Neutrino family patterns (representative)

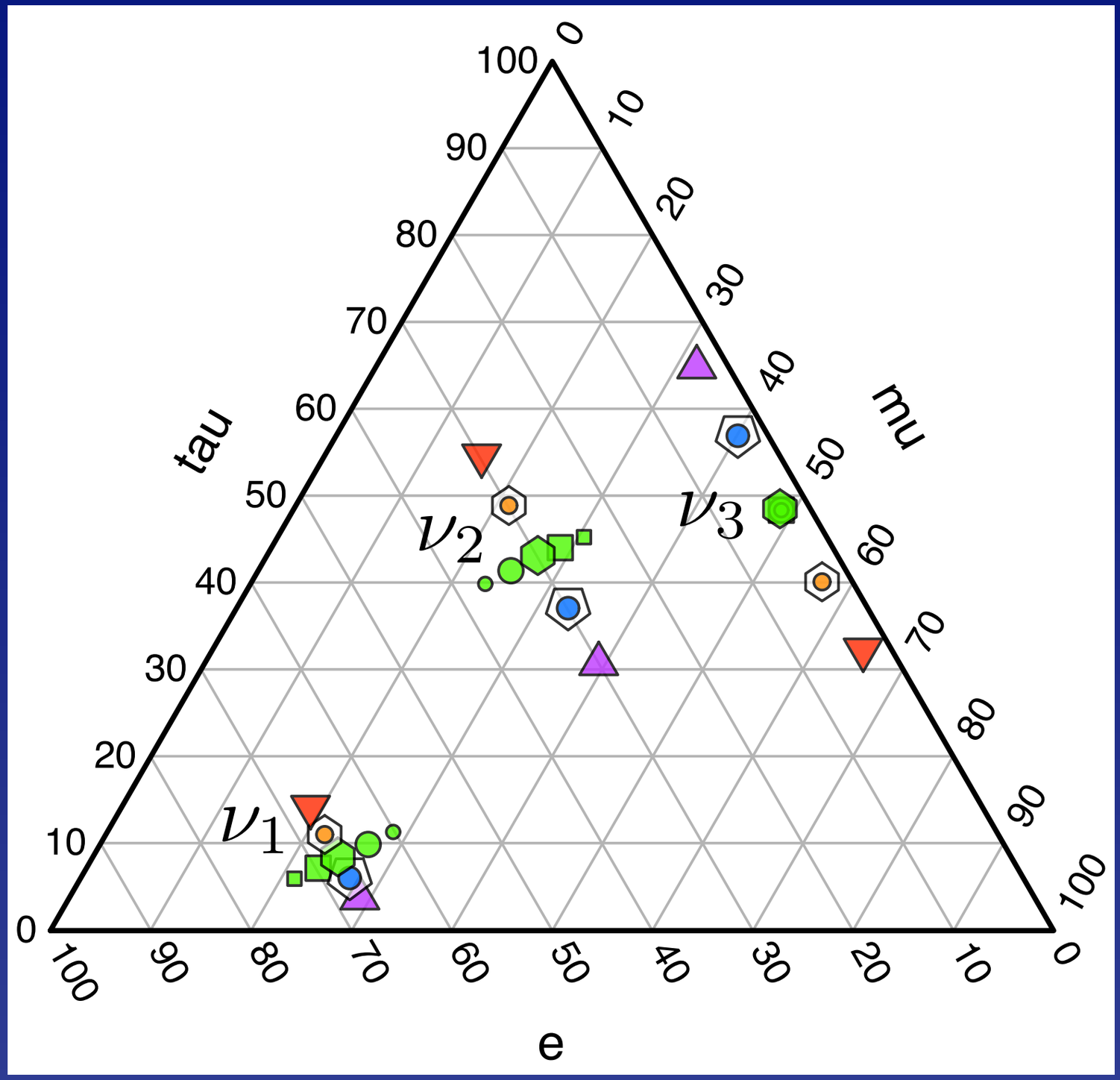


Mena

$m_1 < m_2$; ν_3 lies above or below

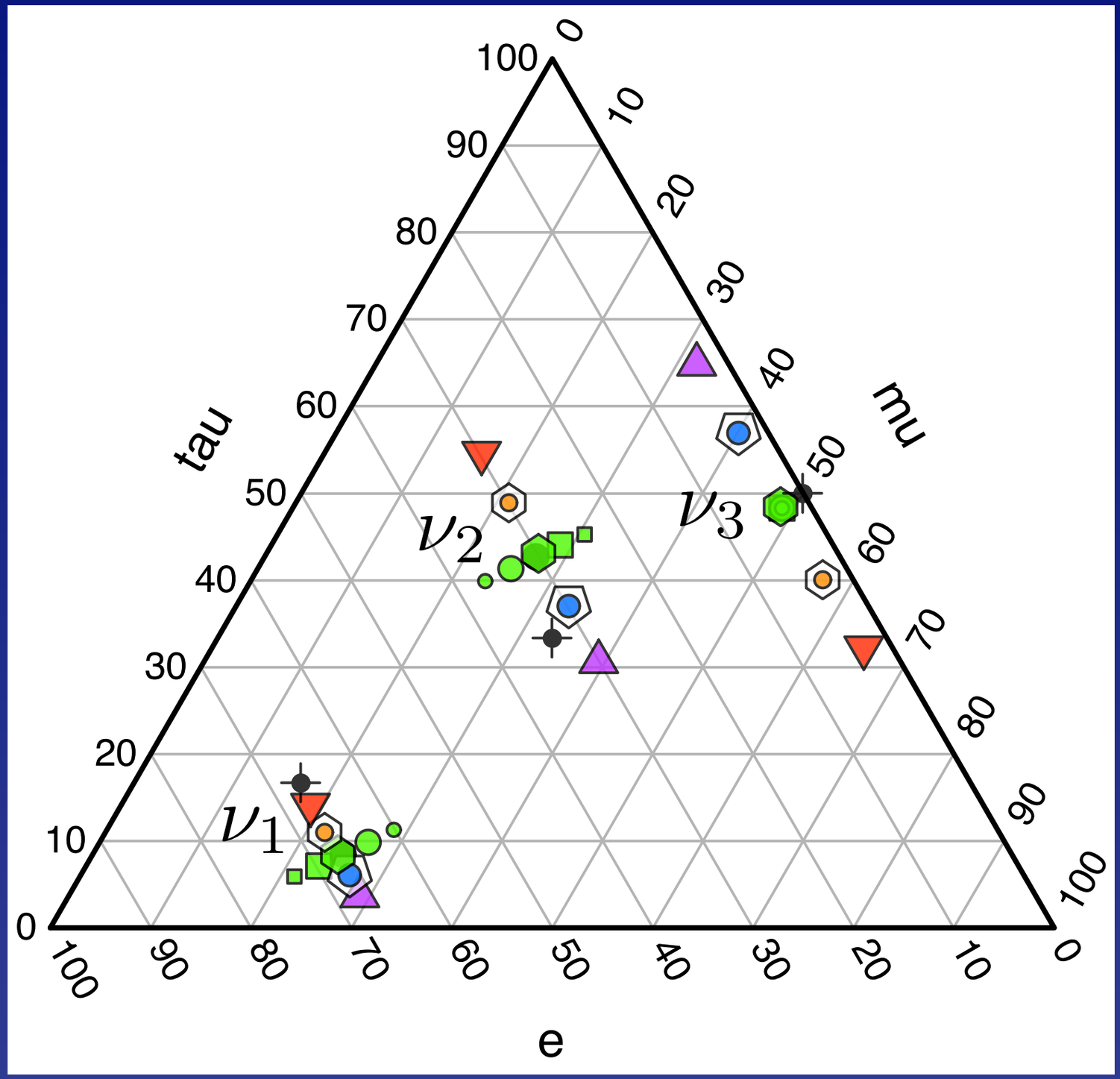
$\theta_{13} = 10^\circ$

Neutrino family patterns (uncertainties)



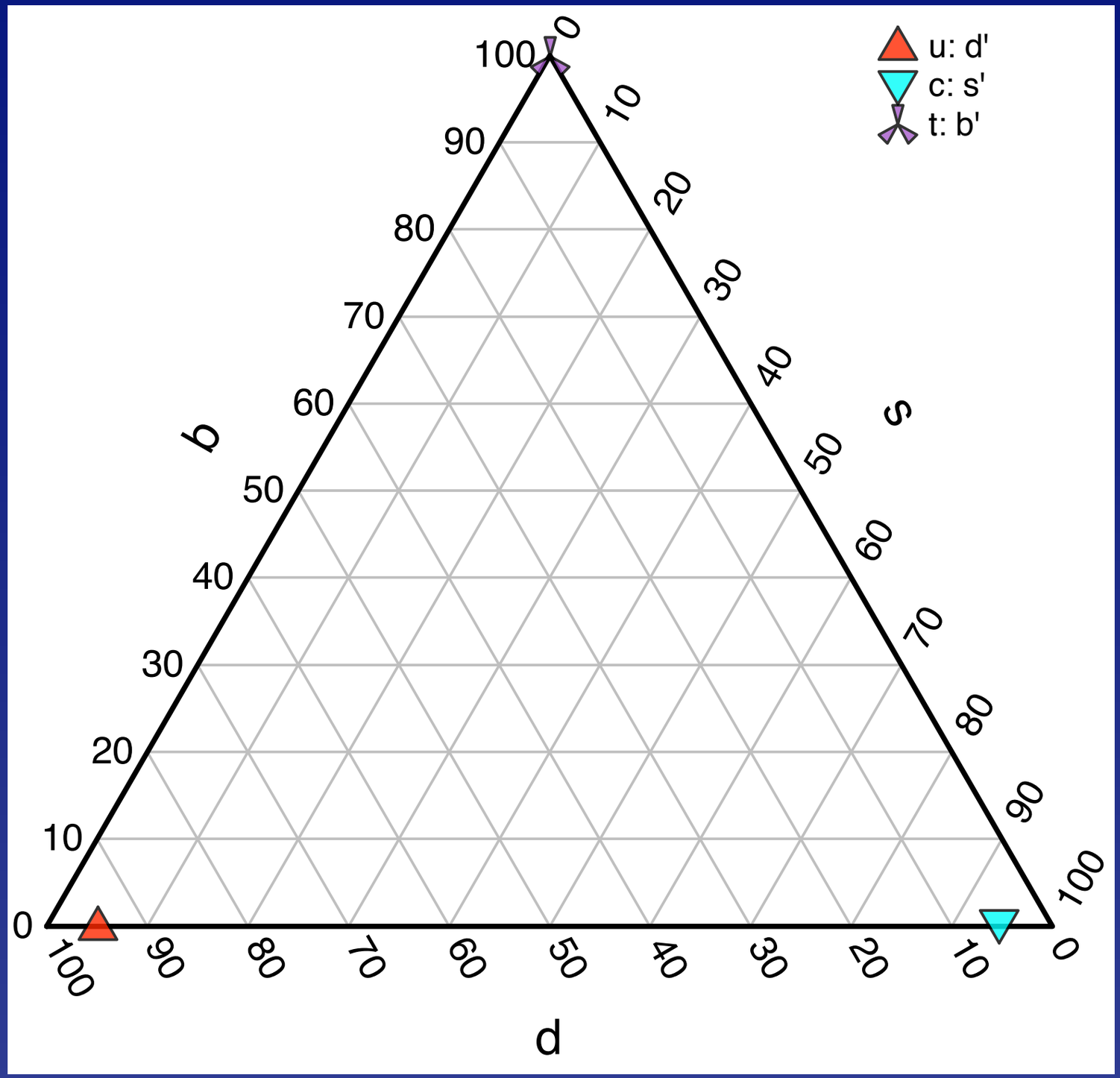
$(\delta = 0)$

Neutrino family patterns (tri-bimaximal mixing)

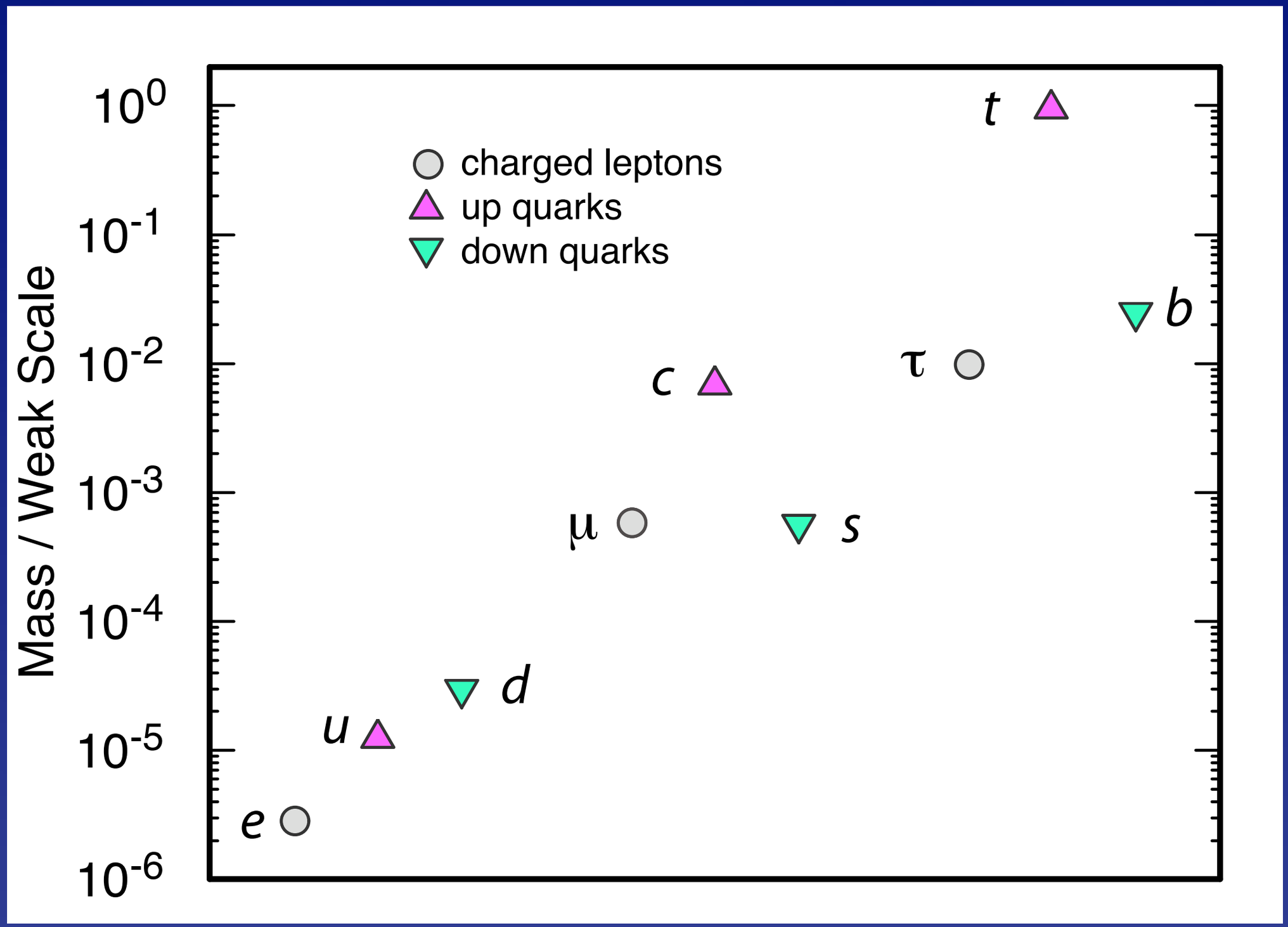


$\theta_{13} = 0,\ \theta_{23} = \text{maximal},\ \sin^2\theta_{12} = \frac{1}{3}$

Quark family patterns

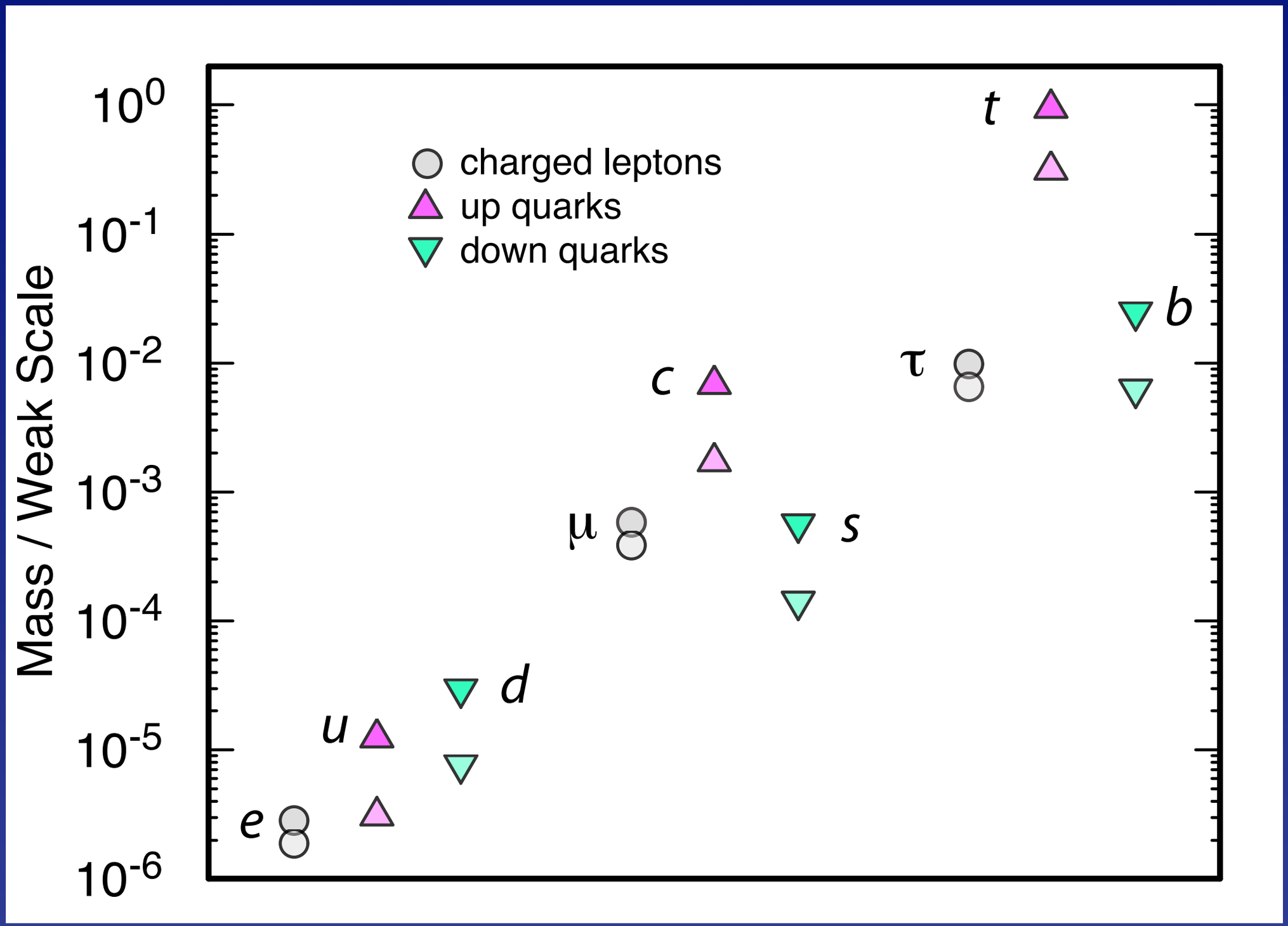


Fermion Masses



Running mass $m(m)$

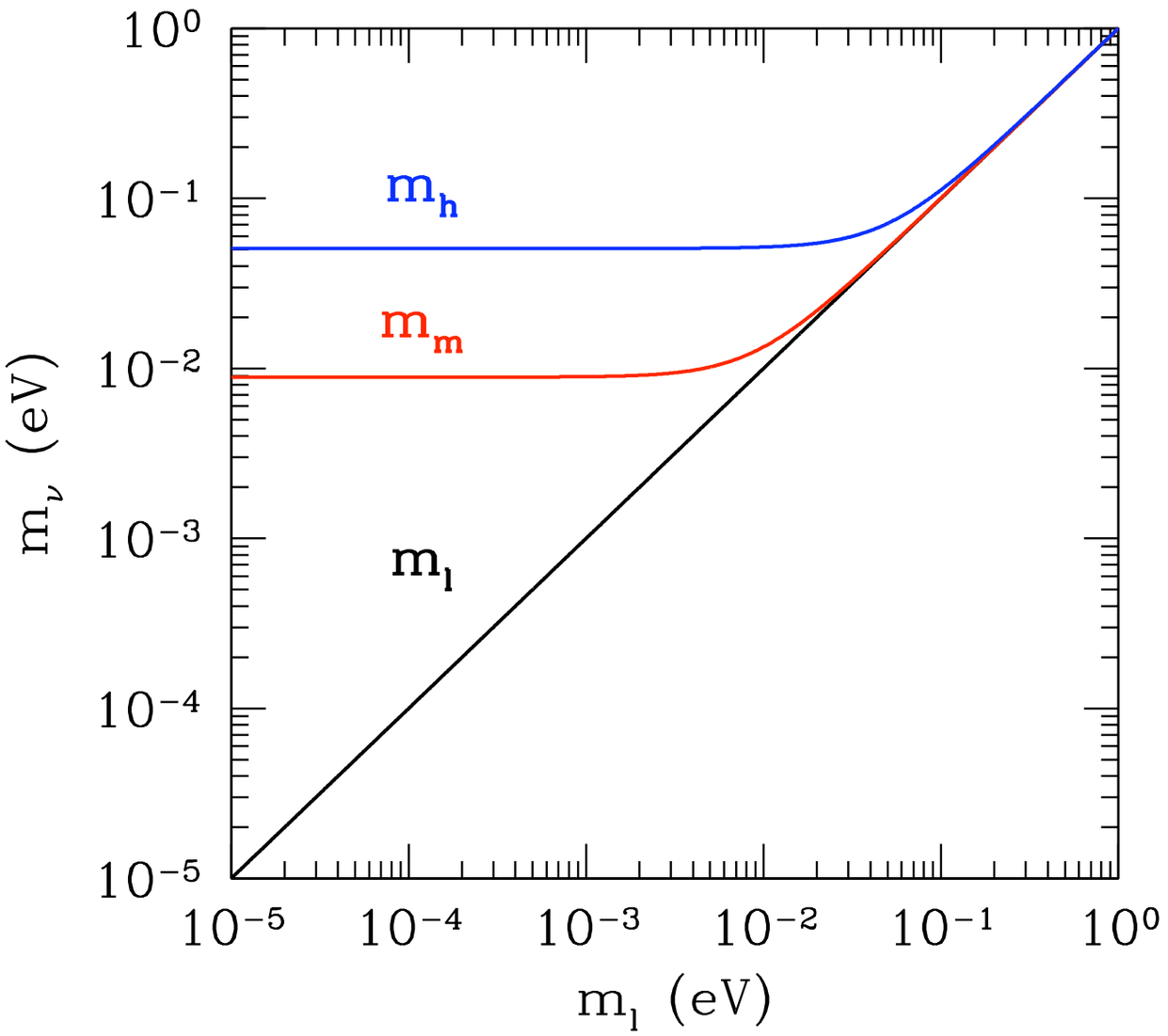
Fermion Masses Run

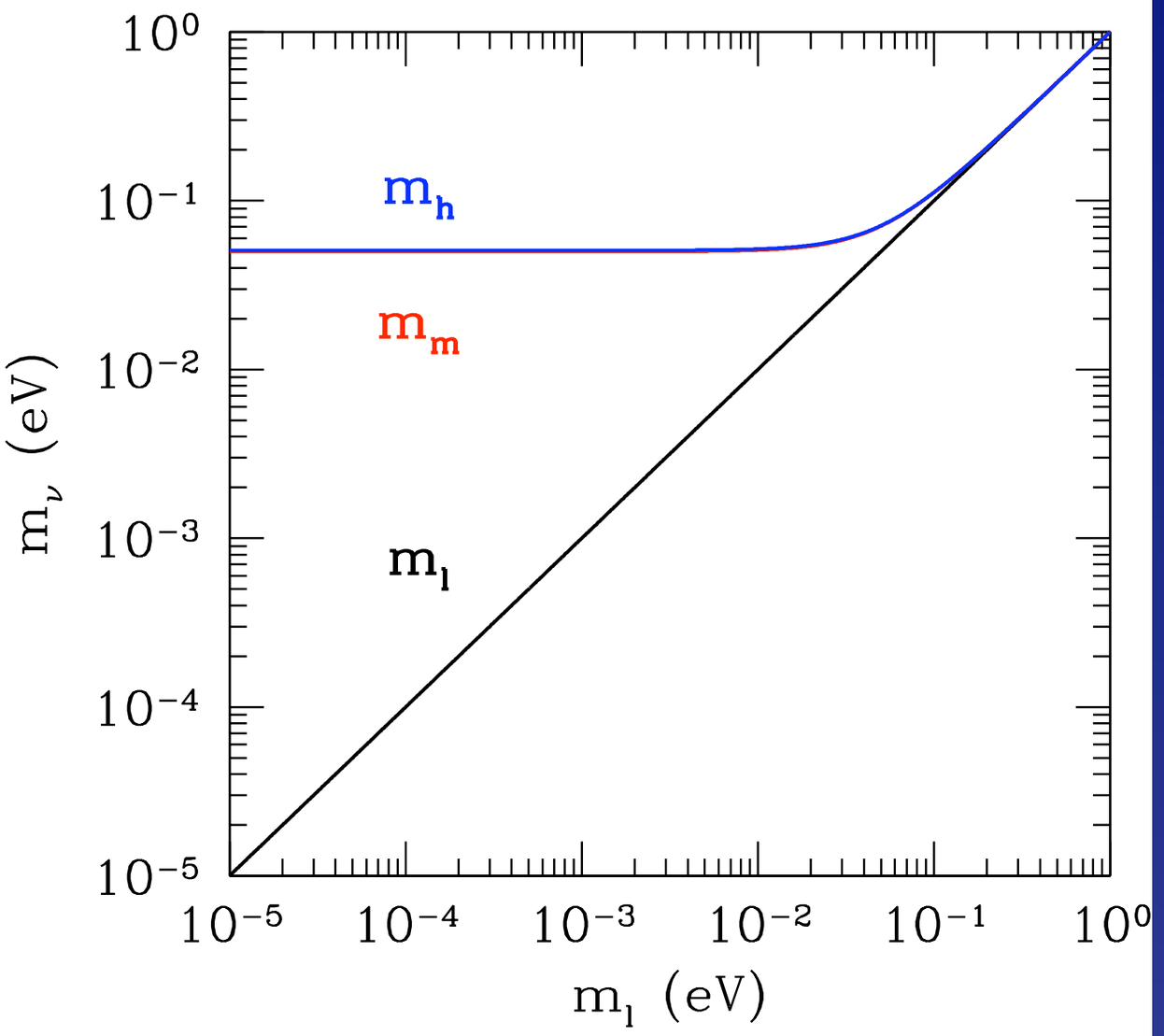


Running mass $m(m)$ … $m(U)$

Neutrino Masses: oscillations determine Δm_ν^2, not m_ν

$$m_2^2 - m_1^2 \approx 7.9 \times 10^{-5}\ \text{eV}^2;\ |m_3^2 - m_1^2| \approx 2.5 \times 10^{-3}\ \text{eV}^2$$

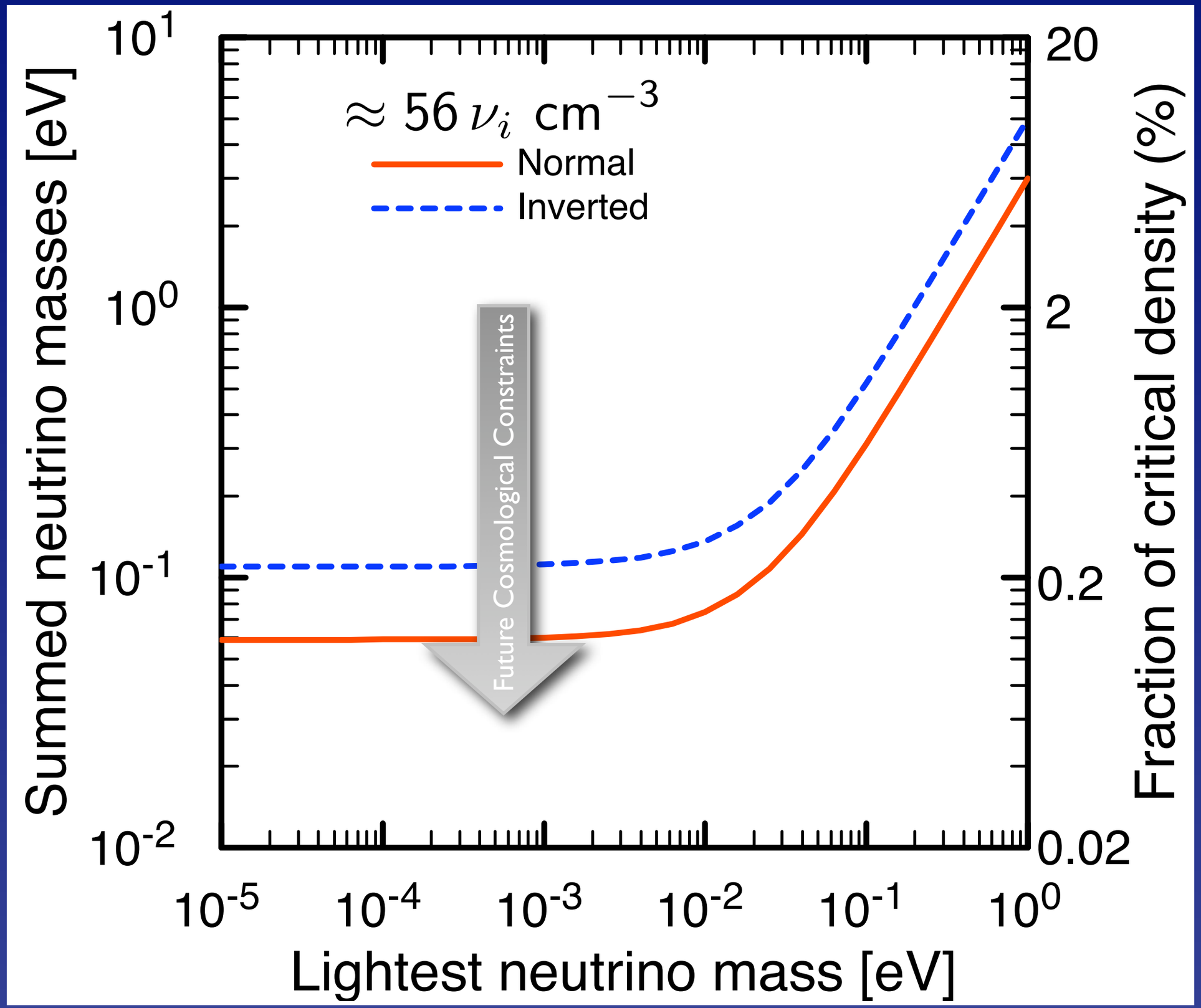




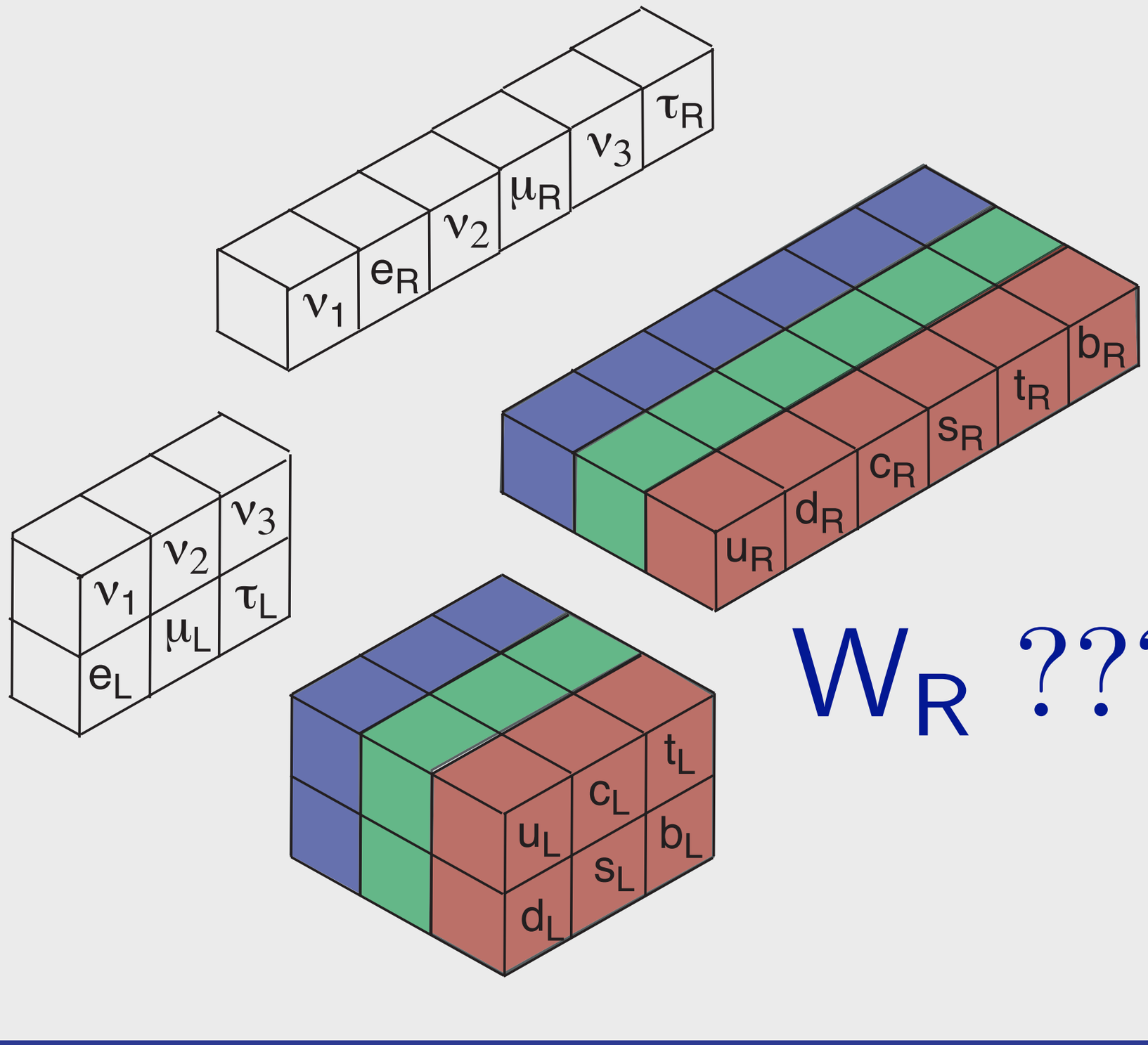
Absolute scale not known, but $m_\nu \lesssim 10^{-5}\ m_e$

KATRIN aims at 0.2 eV

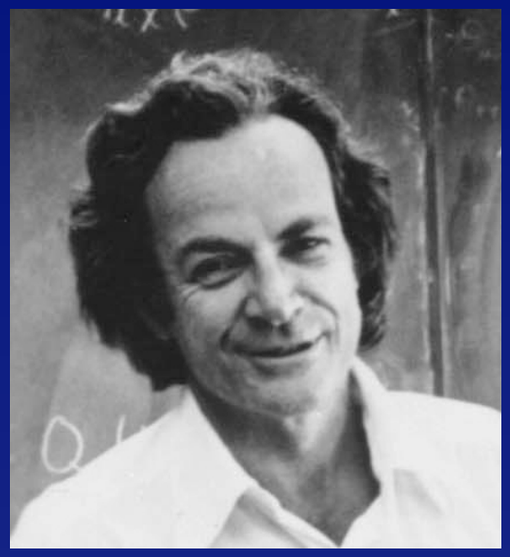
Relic ν contributions to mass density of Universe



Pascoli, Pastor



Interactions: $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ gauge symmetries



Why does the muon weigh?

gauge symmetry allows

$$\zeta_e \left[(\overline{e_{\mathsf{L}}} \Phi) e_{\mathsf{R}} + \overline{e_{\mathsf{R}}} (\Phi^\dagger e_{\mathsf{L}}) \right] \rightsquigarrow m_e = \zeta_e v/\sqrt{2}$$

after spontaneous symmetry breaking

What does the muon weigh?

ζ_e : picked to give right mass, not predicted

fermion mass implies physics beyond the standard model

How could neutrino mass arise?

Add N_R: $SU(2)_L$ singlet with $Y = 0$ — *sterile*
couple ν_L, N_R in Dirac mass term, $\varsigma_\nu \lesssim 10^{-11}$

ν has no charge or color,
so $\nu \equiv \overline{\nu}$ is possible (Majorana)

Dirac & Majorana: explain m_ν ?

Neutrino mass as physics beyond standard model:
may connect with ultrahigh scales (seesaw)
but might also implicate TeV scale

The Importance of the 1-TeV Scale

EW theory does not predict Higgs-boson mass

Thought experiment: *conditional upper bound*

$W_L^+W_L^-, Z_L^0Z_L^0, HH, HZ_L^0$ satisfy *s*-wave unitarity,

provided $\boxed{M_H \leq \left(8\pi\sqrt{2}/3G_F\right)^{1/2} = 1 \text{ TeV}}$

- If bound is respected, perturbation theory is everywhere reliable
- If not, weak interactions among $W^{\pm}$, Z, H become strong on 1-TeV scale

New phenomena are to be found around 1 TeV

Imagine a world without a Higgs mechanism

If electroweak symmetry were not hidden …

- Massless quarks and leptons
- QCD confines quarks into color-singlet hadrons
- *Nucleon mass little changed*
- QCD breaks EW symmetry, gives tiny W, Z masses; weak-isospin force doesn't confine
- *p outweighs n:* rapid β-decay
  ⇒ lightest nucleus is *n* … no hydrogen atom
- Some light elements from BBN, but ∞ Bohr radius
- No atoms means no chemistry, no stable composite structures like liquids, solids, …

… character of the physical world would be profoundly changed

Parameters of the Standard Model

3	coupling parameters $\alpha_s, \alpha_{\mathsf{em}}, \sin^2\theta_W$
2	parameters of the Higgs potential
1	vacuum phase (QCD)
6	quark masses
3	quark mixing angles
1	CP-violating phase
3	charged-lepton masses
3	neutrino masses
3	leptonic mixing angles
1	leptonic CP-violating phase (+ Majorana . . .)
26^+	arbitrary parameters

Flavor physics may be where we see, or diagnose, the break in the SM.

What is the nature of the mysterious new force that hides electroweak symmetry?

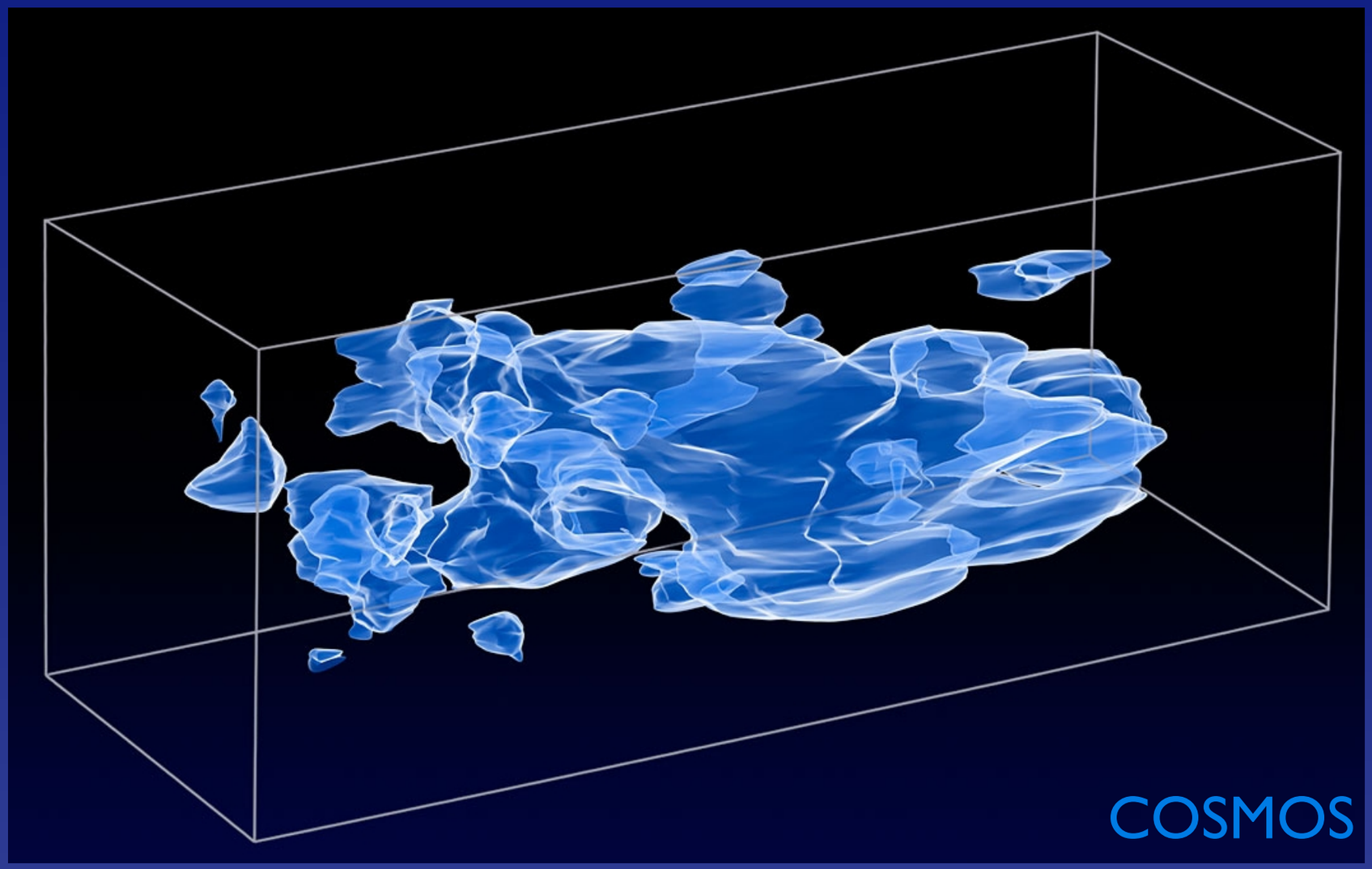
- A force of a new character, based on interactions of an elementary scalar
- A new gauge force, perhaps acting on undiscovered constituents
- A residual force that emerges from strong dynamics among electroweak gauge bosons
- An echo of extra spacetime dimensions

Essential step toward understanding the new force that shapes our world:
Find the Higgs boson and explore its properties.

- ✳ Is it there? How many?
- ✳ Verify quantum numbers (spin, parity, …)
- ✳ Does *H* generate mass for gauge bosons and for fermions?
- ✳ How does *H* interact with itself?

More New Physics on the Fermi Scale?

If dark matter interacts weakly …

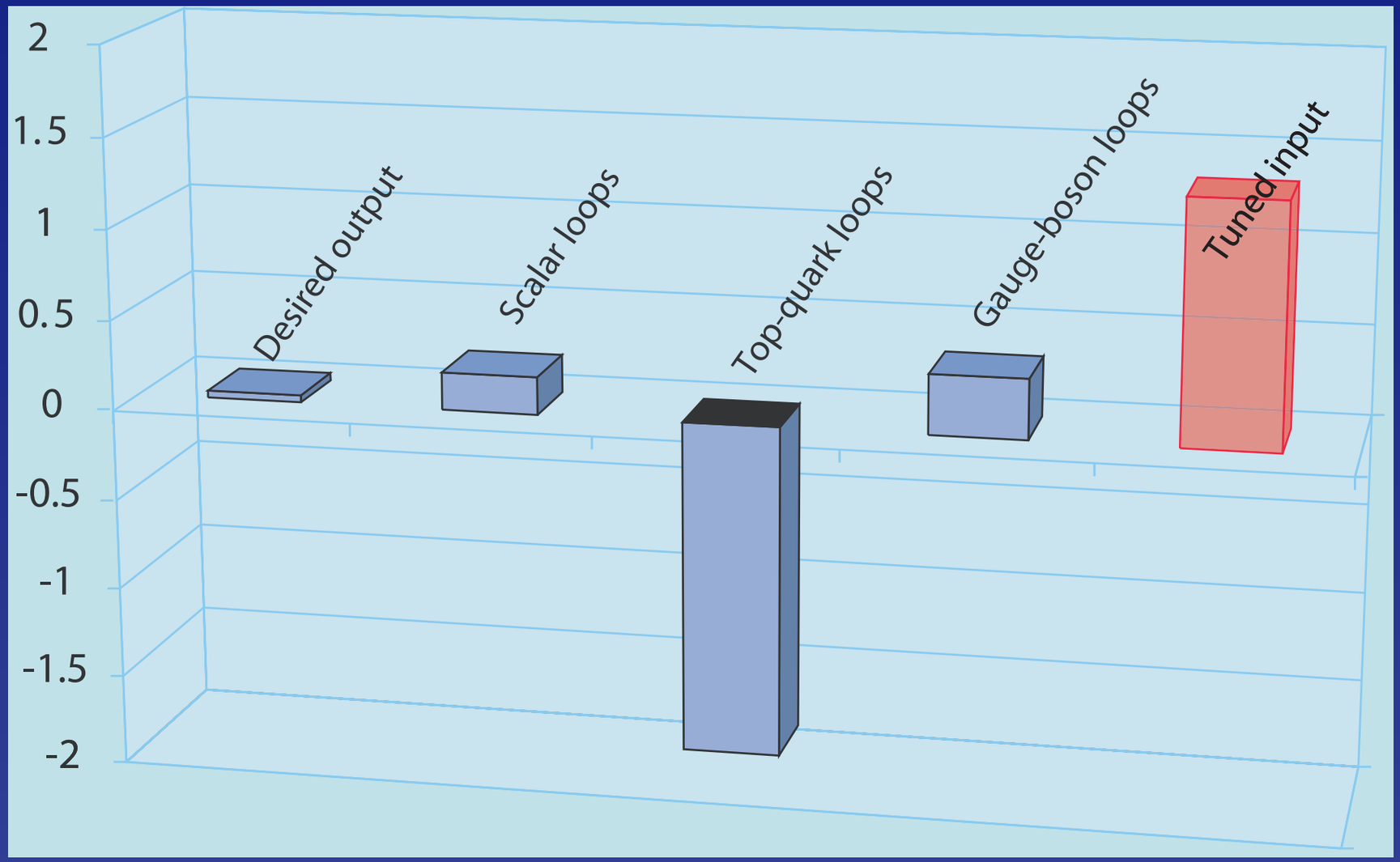


… its likely mass is 0.1 to 1 TeV: *Fermi scale*

How to separate EW, higher scales?

Does M_H < 1 TeV make sense?

The peril of quantum corrections – hierarchy problem



5 TeV

How to separate EW, higher scales?

Traditional: change electroweak theory to understand why M_H, electroweak scale $\ll M_{\text{Planck}}$

To resolve hierarchy problem: extend standard model on the 1-TeV scale …

$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$

composite Higgs boson

technicolor / topcolor

supersymmetry

…

Ask instead why gravity is so weak, why $M_{\text{Planck}} \gg$ electroweak scale

☞ extra dimensions

Look forward to immensely productive conversations
among LHC discoveries, neutrino advances,
other high-sensitivity accelerator experiments,
and astro/cosmo/particle observations

Many examples of possible connections
presented at NuFact08

Lifting the electroweak veil around 1 TeV
should help us to see the problem of identity (flavor)
and the challenges of other scales more clearly

How is our thinking too narrow?

New physics *in* the standard model?

What phenomena are implied by the standard model, but too subtle to have attracted our notice?

Known example: sphaleron for *B*-violation

Recent case: $Z\gamma\omega$ anomaly-mediated $\nu\gamma$ interaction in presence of baryons (Harvey, Hill, & Hill)

Added motivation to measure & understand

ν cross sections, hadroproduction at low energies

HARP, MIPP, SciBooNE, Minerva, MiniBooNE, T2K, …

Catanesi, Harris, Nakaya, Petti, …

What preconceptions must we reexamine?

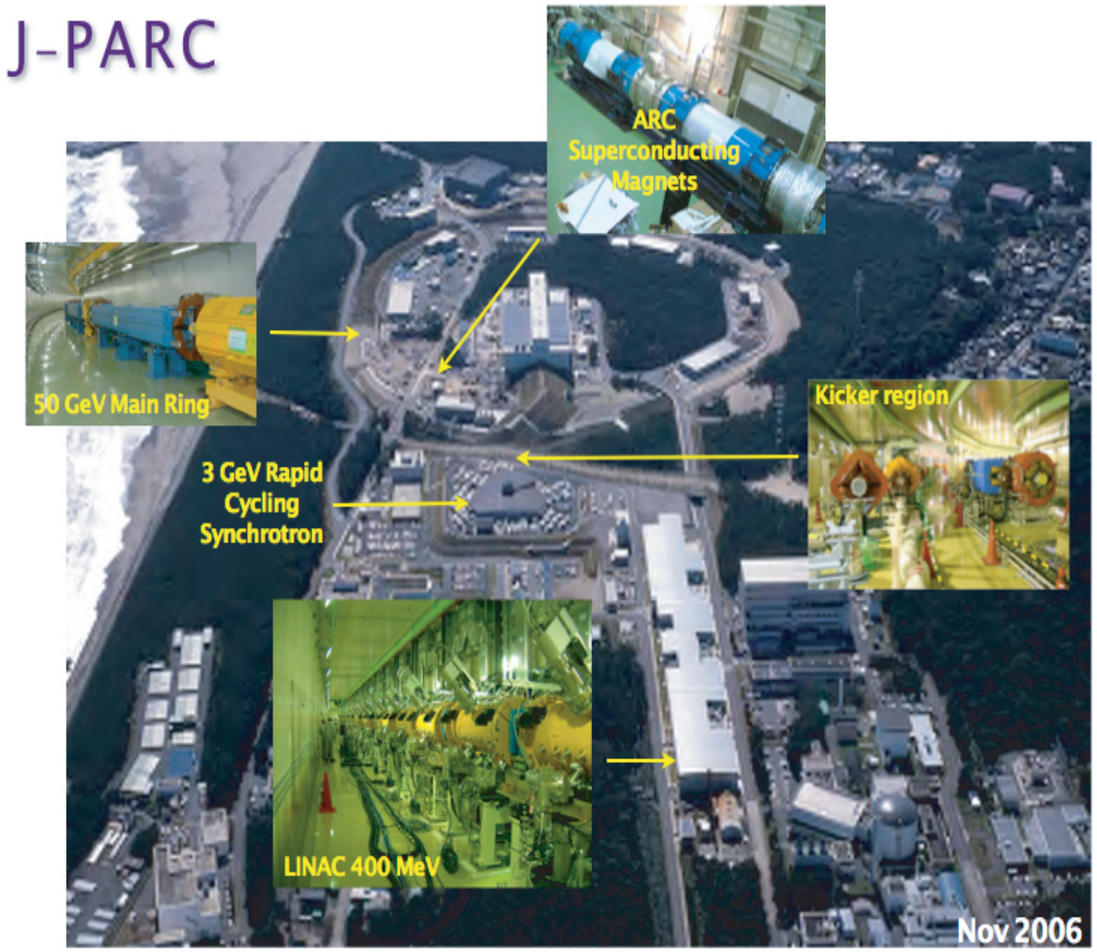
Enormously impressive progress reported here

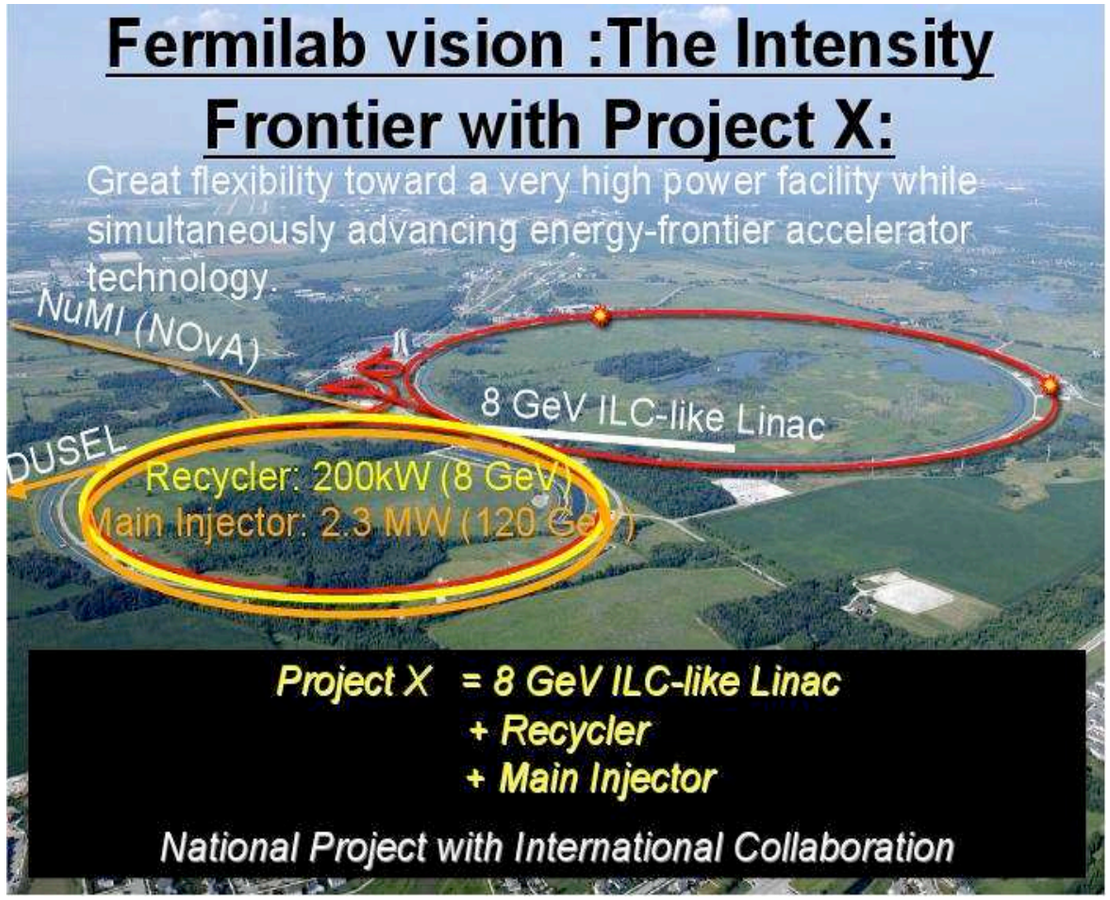
Coherence of experimental results
Breadth of scientific opportunities
Creativity of machine designers

Much incentive to stretch our minds,
think "blue-sky" thoughts
about machines, detectors, baselines, strategies …

and even to ask how little we could require

Super Beams





✦ *J-PARC facility in Japan:*

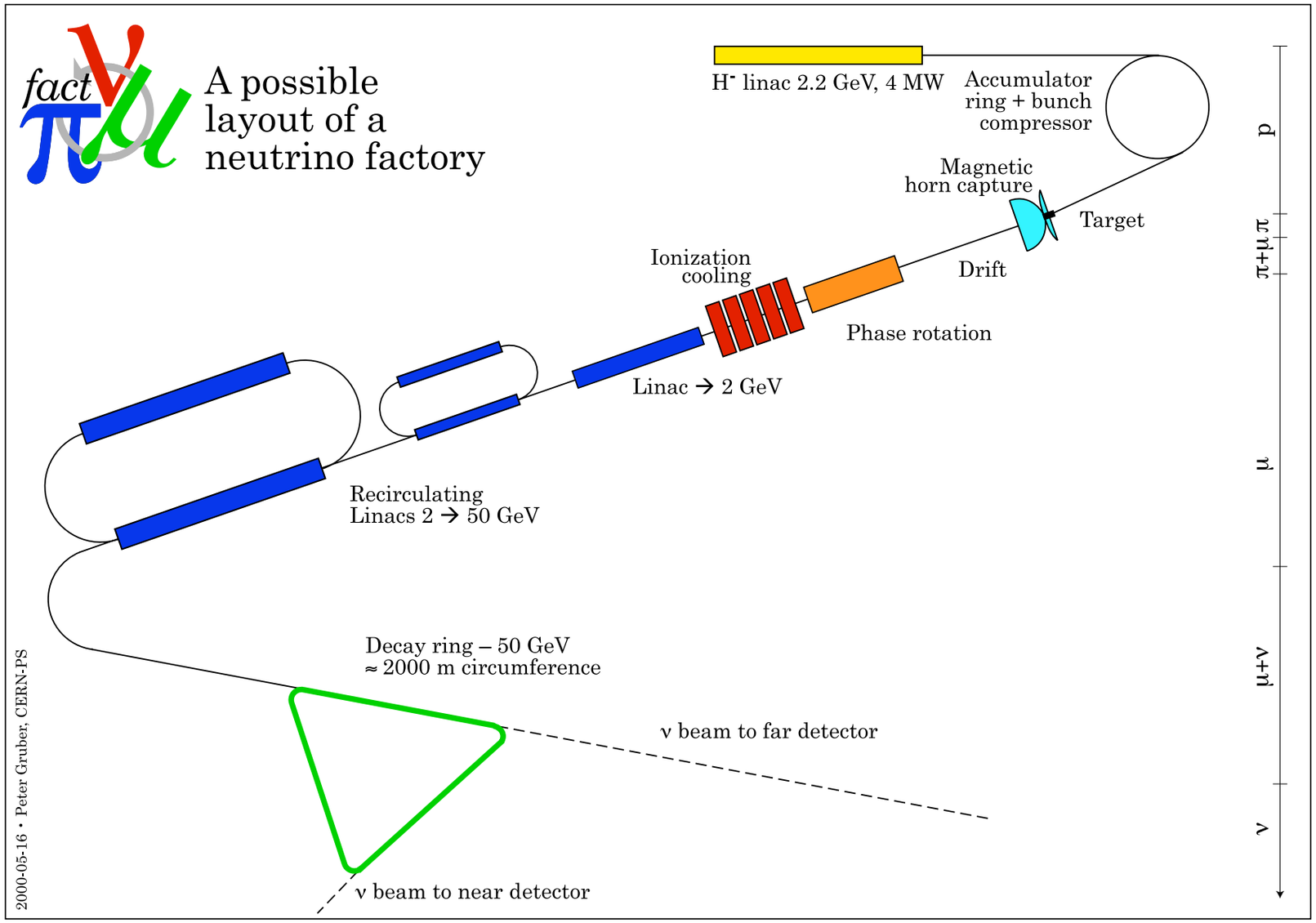
- *Phase I for T2K (2009):*
  0.75 MW 30 GeV, 10×10^{20} *pot/y;*
- *Phase II upgrade (2015):*
  4MW 50 GeV, 50×10^{20} *pot/y*

✦ *Project-X at Fermilab:*

- *NuMI for NOνA:*
  400kW, 700kW MI 120 GeV, 6×10^{20} *pot/y;*
- *New GeV linac + recycler + MI (2016):*
  2.3 MW 120 GeV, 30×10^{20} *pot/y.*

(see talk by D. Harris & A. Jansson)

Neutrino Factory



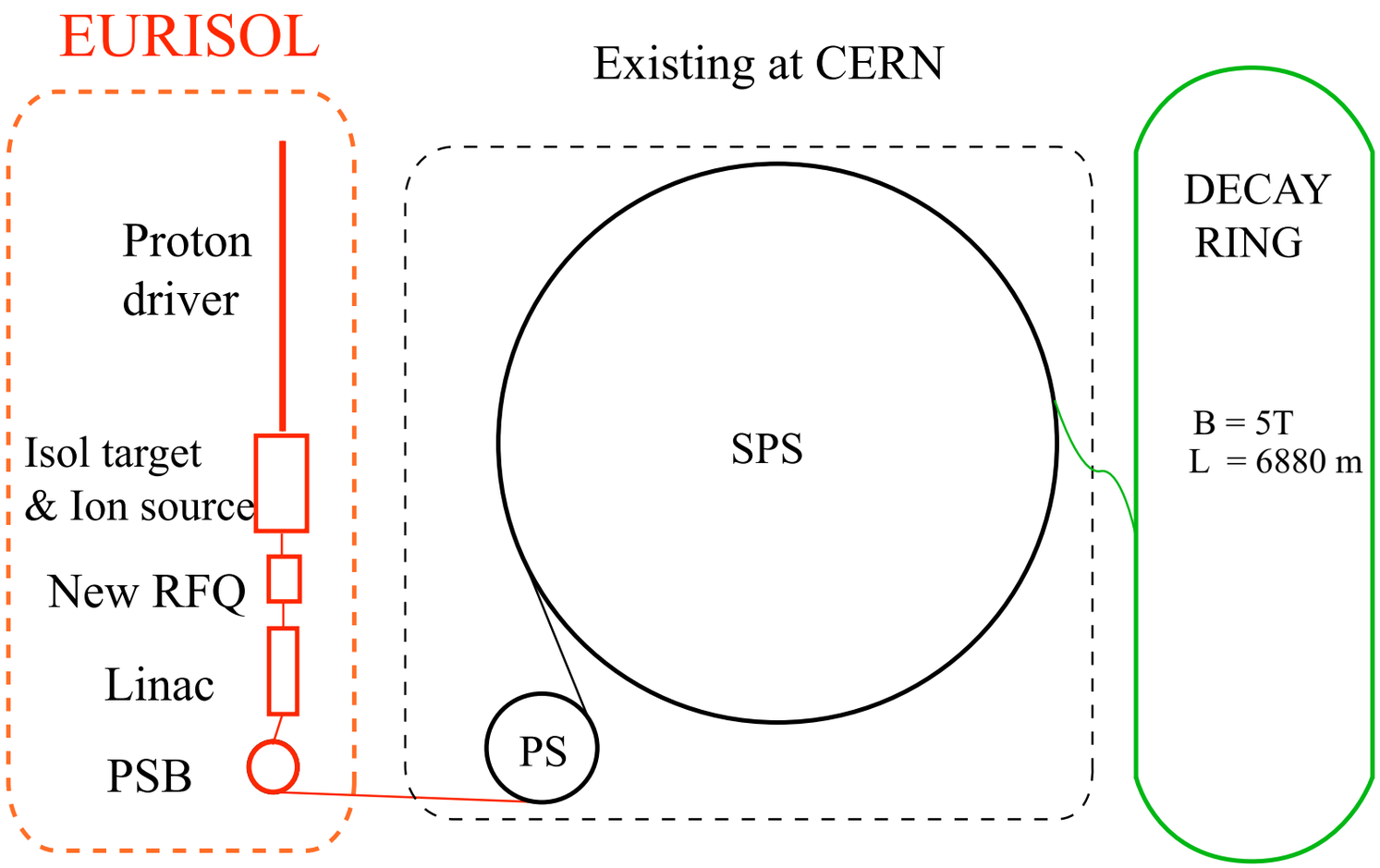
- *Megawatt proton source of few GeV for pion production*
- *Neutrinos produced from decay of 25-50 GeV stored muons*

$\Longrightarrow$ *Useful decays achievable* $3 \div 5 \times 10^{20}$ *per year*

Bross, Palmer, Kirk

Path toward Muon Collider

β Beams



- *Megawatt proton driver of few GeV to produce radioactive ions (ISOL target)*
- *Neutrinos originated from β decay of accelerated ions (EURISOL)*

$\Longrightarrow$ *Rates of* $2.9 \times 10^{18} \bar{\nu}$ *(*^{6}*He) and* $1.1 \times 10^{18} \nu$ *(*^{18}*Ne) per year at* $\gamma = 100$

+ ^{8}Li, ^{8}B, EC monochromatic beams

Wildner

From existing detectors to a new generation

Magnetized iron
Water Cherenkov
Magnetized emulsion
Totally active scintillator
Liquid argon
…

Where do we want to go?

How can we get there?

Practical considerations will intervene

Cavern size, structural integrity, excavation time
Detector cost, fabrication time
Difficulty, cost of steep dip angles

What compromises will get us
to the essential physics results
in the shortest time?

Realizing Neutrino Factory or β Beam

When will needed demonstrations be in hand?
When will experimental specification be needed?

When might we hope to ask for funding?
How long to operations?

Bagnères-de-Bigorre, 1953

the "last" cosmic-ray conference

the coming of the BNL Cosmotron

C. F. Powell: "Gentlemen, we have been invaded!
The accelerators are here."

Louis Leprince-Ringuet: « Mais nous devons aller vite,
nous devons courir sans ralentir notre cadence :
nous sommes poursuivis …
nous sommes poursuivis par les machines ! »

NuFact08: *Updated Questions of Identity*

What are subdominant neutrino transitions?

What is the neutrino hierarchy, absolute mass scale?

Is neutrino mass a sign of nontrivial BSM physics?

Bottom line on LSND & MiniBooNE?

Can we find evidence for a sterile ν?

Dirac or Majorana (*L*-number), scale ≫ EW, GUTs?

Connection between ν mass, LFV, what else?

How could *light* sterile ν arise?

θ_{23}: is ν_3 mostly ν_μ or ν_τ? How small is θ_{13}?

Do ν masses probe large extra dimensions?

Can we detect CP violation in ν mixing?

Does leptogenesis explain matter excess?

How do neutrinos shape the universe?

ν decay, EDM, MDM, discrete symmetry violation?

Thanks to all!